# The care & feeding of solar batteries

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I have been receiving many questions from readers and visitors to the *BHM* web site concerning deep discharge solar batteries. These questions include: How do they work? Which type is best? How long will they last? Are they dangerous? Do they require maintenance? Can they be located outside? How low can they be discharged? How do you clean them?

There are all kinds of batteries, using all kinds of materials. Battery technology is rapidly advancing to increase power density and reduce weight for everything from cell phones to electric vehicles. Unfortunately, this usually requires more toxic materials and a much higher cost. When it comes to choosing a battery for an off-grid solar home or back-up emergency power system, we usually are not that concerned with battery size or weight. We just want a battery that can be quickly charged, then supply power slowly for one or more days, and last six or more years. With all this battery research, it is still hard to beat the lowly deep-cycle lead-acid battery for this type of solar system performance and low cost.

Rack-mounted solar gel-cell sealed batteries

Since any battery is stored chemical energy, perhaps a brief review of basic battery construction and the chemical to energy conversion process is in order.

## Solar battery types

If you want to avoid all battery maintenance, you can purchase sealed "gel" or absorbed glass-matt (AGM) type lead-acid batteries. These have the sulfuric acid converted to a jelly-like consistency, or absorbed in a sponge blanket surrounding the individual lead plates, with the entire battery sealed at the factory. They can be mounted in any direction and are used in solar applications that cannot receive regular maintenance, like solar-powered street lights and remote cell phone towers. Since sealed batteries do not need regular maintenance, they can be stacked closely together.

Unfortunately, maintenance-free lead-acid batteries have a much higher price tag without gaining any more amp-hour capacity than an equal-sized open lead-acid battery. A sealed battery is also very sensitive to charging voltage, and even a slight overcharge can release hydrogen gas and cause rapid battery heating and permanent damage. A sealed battery cannot be equalize charged, since any release of hydrogen gas through the safety pressure relief valve cannot be replaced, so the battery will soon dry out. This usually results in a much shorter life for sealed batteries.

Most off-grid solar and battery back-up systems use an open-cap deep-discharge liquid lead-acid battery. The battery bank will be a group of individual 2 or 6-volt deep cycle batteries wired together to provide a higher system voltage. For small systems, the "L-16" size traction battery is the battery of choice. It has the

same base size as a golf cart battery, but is taller and much heavier. It was originally designed to power battery floor sweepers, fork trucks, and mining cars, and is very ruggedly constructed. It is also available at most battery distributors for a reasonable price, and can have up to six-years of useful life for most solar applications.

If handling and transporting a heavy battery is not a problem for you, larger solar applications can use a "tray" battery. This battery is made up of very tall 2-volt cells, pre-wired into a 12, 24, or 48-volt configuration and housed in a metal box, like the 24-volt tray battery pictured. With individual tray batteries weighing up to a ton, many installers prefer using individual cells and make the battery interconnects after the individual cells are moved to the job site. Although difficult to handle, the tray battery's cells are very tall, providing lots of room at the top for reserve electrolyte, and lots of space at the bottom for flaked off sulfates. The industrial tray battery will last longer than the smaller 6-volt batteries, and an 8 to 12-year life is possible with proper maintenance.

*24-volt industrial tray solar battery*

## Battery chemistry

Lead-acid batteries can be divided into two basic subcategories: lead-antimony and lead-calcium. Since pure lead would be too soft to form the battery plates, several other materials are added to improve plate strength and charge performance. When antimony is combined to make the lead plate stronger, it also improves how low the battery can be repeatedly discharged without damage.

Many deep-cycle lead-antimony batteries can withstand a daily discharge down to 20% remaining charge without any damage. Since lead-antimony plates release much more hydrogen than other battery types, this battery will require more watering and have more out-gassing during the charging process.

When calcium is added to a pure lead plate, this also improves plate strength, but this battery type will have a much lower rate of water loss. This battery is usually referred to as "maintenance-free," and may include sealed cell caps designed to recombine the vented hydrogen and oxygen gasses back into water during the charging process. A car battery is an example of a lead-calcium battery. Before deciding that a lead-calcium battery is right for your needs, please note that for the same size battery, a lead-antimony battery can store up to three times the amp-hours of a lead-calcium battery, because the lead-calcium (low maintenance) battery cannot be repeatedly discharged below 75% full (25 percent used) without damage.

For those of you who still remember high school chemistry, the positive (+) lead plate is covered with a paste of lead dioxide ($PbO^2$). The negative (-) lead plate is called "sponge" lead (Pb). Both are fairly soft, and are formed into a waffle shape to increase the amount of surface area exposed to the sulfuric acid ($H^2SO^4$). The plates are separated from physical contact by a porous spacer or fiberglass matt.

During discharge, oxygen molecules ($O^2$) from the positive plate combine with hydrogen molecules ($H^2$) from the acid to form water ($H^2O$). The now free sulfate molecule ($SO^4$) in the acid then combines with the lead in the positive plate to form lead sulfate ($PbSO^4$).

On the nearby negative plate, the lead in the plate also combines with the free sulfate molecules ($SO^4$) to form lead sulfate ($PbSO^4$). This discharge process causes the acid to become diluted when the battery is fully discharged, due to the chemical conversion of acid molecules into water molecules.

In fact, a battery that is 75 percent discharged can freeze at no colder than 3 degrees due to this change in acid concentration. However, a fully charged liquid lead-acid battery will not freeze until 70 degrees below zero. Always try to locate a battery where it will not exceed 90 degrees, or fall below 50 degrees, with 77 degrees the ideal temperature for maximum battery performance. Battery efficiency and length of service will drop significantly outside these temperature limits.

During battery charging, a reverse chemical process takes place, as the negative lead plate, now covered with lead sulfate ($PbSO^4$), separates back out into lead (Pb), and the sulfate molecule ($SO^4$) is released back to combine with hydrogen in the water ($H^2O$) to reform sulfuric acid ($H^2SO^4$). The positive lead plate recombines with the left over oxygen molecule in the water releasing hydrogen gas. This is the out-gassing of hydrogen that takes place near the end of every charging cycle, as the battery reaches its fully charged state. At this point a good quality battery charger will "sense" the battery is almost fully recharged, and switch to a small "float" charge to limit out-gassing and water loss.

*Required battery maintenance tools*

## Battery sulfation

Battery sulfation is the normal process of small sulfate crystals ($SO^4$) forming on the surface of the lead plates during the discharge process. If a lead-acid battery is not fully recharged, or if left in a discharged state for a long period, these sulfate crystals will begin to "grow" on the lead plates, just like as a child you grew salt or sugar crystals in an evaporating pan on the window sill.

If allowed to grow larger, these sulfate crystals will "insulate" a larger and larger surface area of the lead plate from the acid, and physically expand against the soft lead plates which can cause permanent deformation. Large sulfate crystals can also "flake off" the plates and pile up at the bottom of the battery cells. If the battery casing has limited space under the plates, they can actually pile high enough to short out the separate (+) and (-) plates. The higher the ambient air temperature, the faster this sulfate building process will take place during the discharged state. Below 60 percent remaining charge, this sulfating process increases dramatically.

Unfortunately, the portion of the lead plates that are now heavily coated with sulfate cannot be completely cleaned of the sulfate during battery charging, although there are some "pulse-type" battery chargers that can correct some of the damage. Sometimes repeated over-charging can partially remove the sulfate buildup, but once the initial damage is done, the battery will never reach its original state again. If you want to avoid battery sulfation from reducing the exposed plate area and charge capacity of your batteries, do not let it start in the first place. Keep all batteries topped off with distilled water and fully charged.

## Battery care and feeding

To keep your solar or emergency power lead-acid battery at peak performance, you will need some basic tools and supplies.

Batteries need water to replenish the constant water loss during each charging cycle as hydrogen gas is released, and only distilled water should be used. You do not want to add "hard" water or water having dissolved solids which can increase this sulfate problem even more.

Before handling battery caps, adding water, or checking individual cells, you need to protect yourself from potential acid spills, splashes, or hydrogen gas ignition.

A full face shield and chemical-resistant heavy-rubber gloves are an absolute must. Do not use those thin throwaway gloves which can tear very easily on sharp corners, and will start to disintegrate when in contact with acid.

You will need a good quality specific gravity electrolyte tester, which is the only accurate way to measure and compare the state of charge of each individual cell. You will also need a squeeze-bulb battery filler which allows removal of acid from an overfilled cell. Never remove liquid from one cell and place in another. Regardless of size, each cell of a lead-acid battery at 77°F will have a specific gravity of 1.260 when 100

*Looking into a lead-acid battery with the cap removed*

percent fully charged, and a reading of 1.150 when the battery has dropped below 25 percent remaining charge. Notice this is a very small change in readings, for a large change in charge. If the readings are taken when the temperature is below 77°F, the specific gravity will read artificially high. When the temperature is above 77°F, the specific gravity will read artificially low. Better quality battery testers will include a thermometer and reading adjustment table.

Use a good quality acid resistant nylon plastic funnel when adding water to any battery cell. You may need to cut off the long tube end to obtain a larger bottom opening that fits better in the short opening space.

When you look into a lead-acid battery cell with the cap removed, you should see liquid covering all metal surfaces of the cells. If you can see a dry lead surface, the cell has a very low liquid acid level and probably is building up sulfate. Distilled water should be added until just below the bottom of the "ring" or dip tube that extends down from the cap. Over-filling will cause the acid to bubble out of the cells during charging, when the battery temperature increases and there is a discharge of hydrogen gas.

You should periodically check several individual battery cells before and after charging. Be sure to note any cell with a specific gravity that is lower than the other cells. Do not take readings just after adding distilled water, as it will be "floating" on the top surface and cause an incorrect reading. I prefer to add distilled water just before starting an equalization charge, which causes good mixing of the added water and acid. I then check again after the equalize charge is complete.

On larger systems, some homeowners use a pre-printed form to record these readings, which are usually taken every three months. This will provide an early indication of any problem or downward trend. If you only sample a few cells each time, be sure to always take your readings from the same cells, and be sure the cells near the end and center of each row of batteries are included, as these will be more representative of the other cells. I have noticed the cells closest to the end of string load connection posts seen to loose the most water. I like to check my battery bank

*Checking battery electrolyte*

at the change of seasons to help remind me when three months have passed. This is noted on all calendars and mentioned in the news as the first day of spring, summer, fall, and winter.

## Equalize charging

Your off-grid or battery back-up power system will use either a solar charge controller, a generator powered inverter, or grid powered charger to keep your battery bank fully charged. However, this day-to-day charging is only replacing the amount of amp-hours that were removed during the last discharge period. Over time and multiple charge/discharge cycles, each individual battery cell will begin to have a different charge level due to minor differences in cell construction and acid concentration.

Eventually, the cell that has the lowest charge capacity will limit the ability of a battery charger to fully recharge all other battery cells that are connected in series with the lowest cell. This condition is usually reached every three to four months in new batteries, but older batteries will need water more often and will require a shorter period between equalize charges. Increased water loss is an early indication of battery aging.

To make the equalize-charging process easier, your battery charger or inverter should have an "equalize" charge mode. This switch or program setpoint temporarily overrides the normal "float" charge voltage of the battery charger, which allows battery charging to continue. In a short period, the fully charged cells will start to "boil off" excess hydrogen gas as the water ($H^2O$) in the acid begins to be converted into hydrogen gas and oxygen.

The battery also starts to heat up and the heavy acid near the bottom of the battery cell starts to mix with the lighter water near the top of the cell. Finally, the lowest charged cells reach their fully charged level and the process is ended. Although different battery sizes and charger amp-ratings will determine the actual time required, a typical equalize charge usually lasts two hours longer after the battery has reached its initial full charge voltage.


*Air-tight insulated battery box with PVC air vents to the outside*

## What about hydrogen?

I am not going to diminish the danger of a battery explosion, but it is also not like the large fireballs in a Hollywood special effects movie either. I have been next to industrial batteries when they exploded and I assure you the sound alone will take five-years off your life. However, unless the hydrogen gas has completely filled up a large room in very high concentrations, there should be no fireball. Most of the battery explosions I witnessed were like a flash, lasting only a fraction of a second, with no smoke or burning parts. Regardless, the real danger is large pieces of acid-covered plastic battery case "shrapnel" flying through the air. This most likely will not cause a fire, but it sure can put your eye out, burn your skin, and permanently damage surrounding surfaces.

Although it may be theoretically possible, I have not heard of any battery "exploding" while supplying power to a load or sitting on the shelf and not being charged. It is also rare for any battery to explode during normal charging, as long as it is in a well ventilated area. The greatest danger is that point when the battery is almost fully charged, but the charger is still operating, or when an equalize-charge is in process and a large quantity of hydrogen gas is being generated.

Hydrogen gas in the air "tastes" salty when you breathe it. It reminds me of being near the ocean, and this is a good indicator that more ventilation is needed. If the battery room is well ventilated, these gases will eventually dissipate and will no longer be concentrated enough to present any danger.

However, if the battery is in a small room or battery enclosure with limited or no means of air ventilation, the hydrogen gas can reach a dangerous level of concentration. Hydrogen gas is only explosive when in high concentrations, which can form near the battery room ceiling or top of a battery enclosure. Note the two PVC vent pipes at the top of the custom built battery box in the photo this page.

Any small spark or nearby flame can cause concentrated hydrogen gas to ignite. It will then travel down through the battery cap vents like a lit fuse on a cannon, where the explosive force of the ignited hydrogen gas in the closed cell cannot escape, resulting in flying battery parts. In one of the larger battery explosions I witnessed, a battery on an electric fork truck exploded after being on charge all day. A tiny spark from a worker's hand grinder over 30-feet away ignited the concentrated hydrogen gas that had formed around and inside the battery at the end of a long charge cycle.

I recently had to replace a sealed 12-volt RV/Marine battery in a trailer, when it exploded and tossed acid and plastic parts in all directions. A tiny "trickle" charger had been left on for several months at the same time the battery was not supplying any loads, which eventually "boiled" the battery dry. It appears the continued charging caused the battery plates to short out or heat up, which ignited the surrounding hydrogen gas. Although there was no fire, it was a real mess to clean up and the acid permanently blackened and softened the surrounding wood walls and floor.

## Periodic battery cleanup

Lead-acid batteries contain sulfuric acid which is very corrosive. If you splash it on your clothes, the threads will eventually dissolve everywhere it made contact. If it gets on wood building materials it will damage the wood. If it gets on concrete, it will damage the concrete. I have already addressed the danger to your eyes and skin.

In addition to normal acid spills and drips during the adding of distilled water, long term battery charging also causes an acid "mist" to settle on the top of the batteries and battery cables, causing corrosion and poor electrical contact at the terminal connections. This surface condition can also allow small electrical currents to flow between the battery terminals, which increase standby charge loss.

Since any acid and "base" forms water and a salt when combined, battery acid can be neutralized when in contact with baking soda (a strong base). I like to mix a bucket of warm water with a half box of baking soda, and wipe all batteries and cables with a cotton rag dripping with the solution. Be sure you do this with all the battery caps tightly secure, as you never want any of the solution to drain down into the battery cells. This solution should always be nearby to control any spills or accidental splashes of battery acid onto skin or clothes.

## Battery myths

Storing a battery on a bare concrete floor will "drain" away the charge. No, a concrete floor surface is usually much colder than a higher wooden garage bench. Placing a battery on a cold concrete floor lowers the battery's state of charge due to the lower temperature.

You can use a car battery for solar applications. No, car batteries have very thin lead plates to reduce vehicle weight, and will quickly fail after only a few deep discharge cycles.

Old lead-acid battery technology is wasteful and contaminates landfills with hazardous wastes. No, lead-acid batteries carry a high refundable cash deposit to ensure the old battery will be exchanged, and almost every part of the old battery will be 100 percent recycled into new batteries.

## Conclusions

This article is not intended to scare a potential solar system buyer. It is however, intended to give everyone a healthy appreciation of how to take care of and work safely around a lead-acid battery bank. These batteries are still the easiest and lowest cost way to store the excess energy from a solar array, wind generator, or hydro turbine, and with regular maintenance, a lead-acid battery will provide many years of safe and trouble-free service.

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